Interaction of Particles and Turbulence in the Solar Nebula

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The most widely accepted theories for the formation of the Solar system claim that small solid particles continue to settle into a thin layer at the midplane of the Solar nebula until it becomes gravitationally unstable and collapses directly into km-sized planetesimals. This scenario has been challenged on at least two grounds: (1) due to turbulence, the particles may not settle into a thin layer, and (2) a thin layer may not be unstable.

The Solar nebula contains at least three sources of turbulence: radial shear, vertical shear, and thermal convection. The first of these is small and probably negligible, while the last is poorly understood. However, the second contribution is likely to be substantial. The particle-rich layer rotates at nearly the Keplerian speed, but the surrounding gaseous nebula rotates slower because it is partly supported by pressure. The resulting shear generates a turbulent boundary layer which stirs the particles away from the midplane, and forestalls gravitational instabilty.

Our previous work used a "zero-equation" (Prandtl) model to predict the intensity of shear-generated turbulence, and enabled us to demonstrate numerically that settling of particles to the midplane is self-limiting. However, we neglected the possibility that mass loading by particles might damp the turbulence. To explore this, we have developed a more sophisticated "one-equation" model which incorporates local generation, transport, and dissipation of turbulence, as well as explicit damping of turbulence by particles. We also include a background level of global turbulence to represent other sources. Our results indicate that damping flattens the distribution of particles somewhat, but that background turbulence thickens the particle layer.

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